Volume 38 June, 1952 *Number 6*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

ELECTRIC POWER—
STEAM TURBINE
LUBRICATION

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

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Published by

The Texas Company, 135 East 42nd Street, New York 17, N. Y.

Vol. XXXVIII June, 1952 No. 6

Electric Power — Steam Turbine Lubrication

THE electric industry has grown to its present status in a little more than fifty years. The key to this phenomenal growth has been the steam turbine. When the electric generator had to be driven by a steam engine, electrical output was low, fuel consumption per kilowatt hour was high and flexibility of operation was extremely limited. The steam turbine corrected these limitations.

The first sizeable electric generator powered by a steam turbine was installed in 1900; the capacity of this unit was 2000 kilowatts and it was considered to be tops in its concept and design. Today steam turbines up to 200,000 kilowatts capacity are built for stationary service and up to 53,000 horsepower for marine operations.

Electric power load has grown at the rate of six per cent annually for the past twenty years and this rate of growth is expected to double during the next three years. Power generation by steam turbines has already reached 200 billion kilowatt hours annually and this source of electric power can be expected to predominate in the foreseeable future.

In the modern steam turbine, rotors turn at 900 miles per hour peripheral speed; steam at 2300 pounds pressure passes through the blades at a rate of 1200 miles per hour; steam temperatures drop from a peak of 1100°F. to room temperature in a fraction of a second. These terrific speeds and temperature changes impose most severe demands upon the materials of which the turbine is constructed and upon the oil which is used for its lubrication.

The designers of modern steam turbines have been well aware of the problems connected with each increase in temperature, pressure and power output and have worked closely with the lubricating oil manufacturers to hold the demands upon the oil to a minimum. At the same time they have taken full advantage of advances in petroleum technology, as quickly as possible. Fortunately cost of lubrication is a most insignificant part of the operating expense of a steam turbine so that cost considerations did not hamper improvements in turbine lubricating oil. The value of the amount of power produced annually is fantastic. Equally fantastic is the fact that this vital item in our modern way of living is insured by a tiny fraction of a per cent in terms of cost of lubrication.

HOW THE LUBRICATING OIL FUNCTIONS

In a modern steam turbine, the lubricating oil must perform the following functions:

1. Lubricate the bearings of the turbine and the electrical generator.
2. Act as a cooling medium for the turbine bearings.
3. Lubricate the governor and control mechanism and transmit the governor-varied impulses to the control mechanism.
4. Act as a sealing medium to prevent loss of hydrogen from hydrogen-cooled generator.

5. Prevent the formation of rust and sludge within the confines of the lubricating system.

DESIRABLE PROPERTIES

To perform these lubricating, cooling and protective functions the turbine lubricating oil must have the following desirable properties:

1. It must have the correct viscosity.
2. It must be resistant to oxidation and sludging.
3. It must prevent rusting of ferrous metals with which it comes in contact.
4. It must be non-corrosive to turbine parts.
5. It must be resistant to foaming.
6. It must be able to free itself rapidly from air and water.
7. It must be clean initially and capable of being kept clean in service by the conditioning system provided.
8. It must be capable of being stored for long periods without serious reduction in any of its desirable properties.

Viscosity

The viscosity of turbine oil is dictated by the operations which are performed upon the oil during its circulation and the functions of the oil during this period. The oil is circulated by a pump, passes through a conditioner and cooler, lubricates the bearings and moving parts and acts as a hydraulic medium in the governor system. The viscosity must be high enough to afford satisfactory lubrication and low enough to keep power losses in pumping and in the bearings to a minimum. In the special case of geared turbine systems, the circulating oil must be of sufficient viscosity to lubricate the gears.

Adjustments to the viscosity of the circulating oil are made by adjusting the temperature and the rate of oil flow. While operating conditions will vary, it is considered desirable to hold the bearing outlet temperature of the circulating oil in the neighborhood of 145°F. or at least within the range of 130°-160°F. At the cooler outlet, the circulating oil should be held to a temperature range of 110°-130°F. In no case should the oil be cooled below 100°F., otherwise it might become too viscous.

In the case of auxiliary turbines, equipped with ring-oiled bearings, higher temperatures can be expected at the bearings because of the small volume of oil involved and, frequently, the absence of outside cooling facilities.

For the modern, high-speed steam turbine directly connected to an electric generator in stationary service the accepted viscosity range is from 140 to 250 seconds Saybolt Universal at 100°F. This range is sub-divided so that two oils are available, one having a viscosity of 140 to 170, the other having a viscosity of 175 to 250. For steam turbines direct-connected to generators in marine service a viscosity range of 300 to 350 seconds Saybolt Universal at 100°F. is usually specified.

Where the turbine is connected through gearing, a higher viscosity is necessary since the oil must lubricate both bearings and gears. Small geared turbines powering pumps and blowers are lubricated with an oil having a Saybolt viscosity of 250-350 seconds at 100°F. Large geared turbines, such as marine propulsion equipment, are lubricated with oil having a Saybolt viscosity of 400-560 seconds at 100°F.

Because of the higher temperatures encountered in the lubrication of ring-oiled bearings, and particularly when cooling facilities are not provided, higher viscosities may be required. Viscosity ranges of 250-600 seconds Saybolt at 100°F. are specified for water-cooled ring-oiled bearings and of 600-1700 seconds Saybolt at 100°F. for ring-oiled bearings which are not cooled by external means.

The ranges shown are only general and the turbine operator should be guided by the recommendation of the manufacturer of the turbine as to lubricating oil viscosity and operating temperatures, since exact choice of viscosity will depend upon a number of design factors, such as speed, rate of circulation, bearing clearances, gear tooth load and anticipated temperatures in gears and bearings.

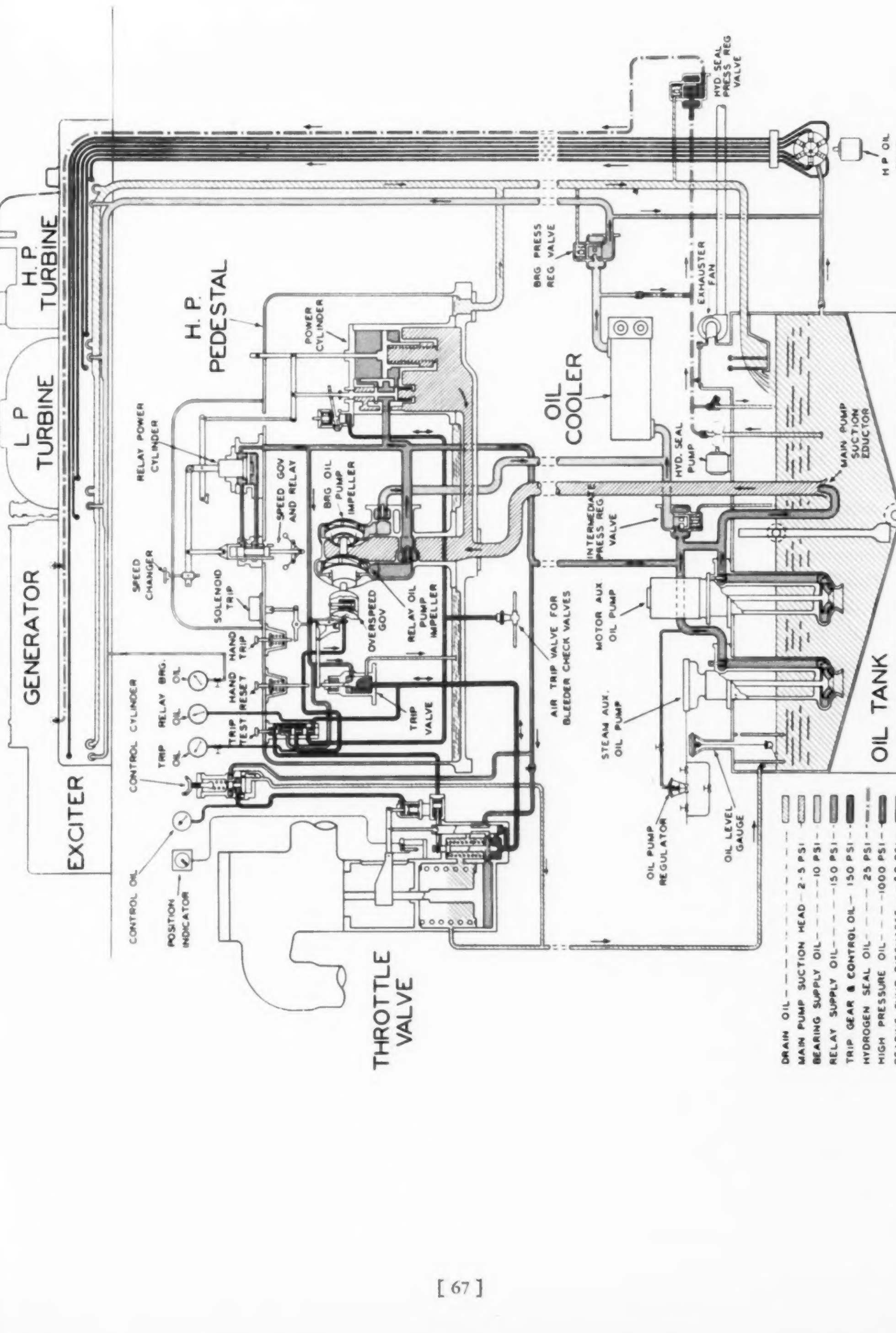
Oxidation Resistance

Lubricating oils are hydrocarbons which can react with oxygen to form oxygenated bodies; these may impair the lubricating qualities and, eventually, as they become insoluble in the oil promote the formation of deposits or sludges with water and foreign suspended matter.

For oxidation to take place, oxygen must be in contact with the oil. The reaction between the oil and oxygen is accelerated by increasing temperature, by metallic catalysts, by water, by foreign suspended matter and by the products of oxidation themselves.

An increase of 18°F. in the temperature of the oil usually will roughly double the rate of oxidation. Thus an oil which gave satisfactory service life where the bearing outlet temperature was 150°F. might show quite unsatisfactory life if the temperature at the bearing outlets was permitted to rise permanently to 180°F. Operating temperatures, therefore, should be held within the limits specified by the turbine manufacturer, usually 130°-160°F.

Oxidation is also promoted by the presence of metals which act as catalysts. Copper, brass, bronze and zinc are particularly effective promoters of



Courtesy of Allis-Chalmers Mfg. Co.

Figure 1 — Details of a typical oiling system for Allis-Chalmers tandem-compound steam turbine.

oxidation. For this reason, galvanized (zinc coated) iron piping or tanks are not recommended and the use of copper and copper alloys is avoided or their effects minimized by tinning surfaces which come in contact with the oil.

Moisture may enter the turbine system through leaks at the sealing glands or at the coolers and through condensation from the atmosphere in the sump tank. The use of vapor extractors on sump tanks has been found to be very helpful in preventing condensation of moisture in the sump. A careful watch should be kept for the presence of moisture in the lubricating oil; if detected, the source should be determined and the difficulty eliminated as soon as possible. The purifier operation should be extended, if necessary, to remove with all possible speed water leaking into the lubricating oil. The proper use of the purifier will also keep the oil free of dirt, dust and foreign material.

The formation and deposition of oxidation products can best be combatted through the use of oxidation inhibitors incorporated in the turbine oil by the refiner. These materials, present in only very small percentages, are very effective in slowing down the rate of oxidation even under severe operating conditions and thus prolonging greatly the useful life of the oil. Such inhibitors are added to the base oil at the refinery. Since these oxidation inhibitors are not equally effective in various brands of turbine oil, it is inadvisable to attempt to compound or re-fortify in the field.

Corrosion Prevention

Corrosion of a turbine lubricating system may occur as a result of electrolytic action, particularly when dissimilar metals are in contact in the presence of an electrolyte; it may also be due to leakage of stray currents because of faulty insulation or inadequate grounding. Electrolytic corrosion can be prevented by the use of electrical insulating materials to prevent physical contact between dissimilar metals. Corrosion due to stray currents can be controlled by periodic inspection and maintenance of ground connectors and bearing insulation.

Oil oxidation products may be corrosive to certain types of babbitt. Certain bearings of high lead content may pit as a result of contact with lubricating oil which has been retained in service for periods long enough for excessive oil oxidation to occur. Steam turbines and generators are usually equipped with high tin babbitt bearings, which are highly resistant to attack by oil oxidation products.

Rust Prevention

In contact with water and air or oxygen, iron or steel surfaces will form various iron oxides, or rust. Highly-refined straight mineral oils of turbine grade are easily displaced by water films from ferrous metal surfaces and they, therefore, present no barrier to water and cannot effectively protect against rusting. Since freshly cleaned or prepared iron surfaces are particularly susceptible to rusting, it is an extremely difficult task to start up a new turbine with straight mineral turbine oil without some rusting occurring in the system. It was known, for many years, that used turbine oils containing oil deterioration products would protect fairly well against rusting; because of this fact, it became a common practice to add 10% used oil to the new turbine oil, in starting up a new turbine system. This practice had the drawback of reducing the anticipated oil service life, because of the presence of oxidation products which would catalyze further oxidation.

After long research, additives were developed for turbine oils which would afford protection against rusting in turbine service and would not detract from the other desirable characteristics of the turbine oil. Such additives are polar materials, which appear to concentrate at the points of contact between oil and ferrous metal when water is present. As a result, at least in part, of the wide-spread use of rust-inhibited turbine oils, rusting in turbine systems has become a very minor problem.

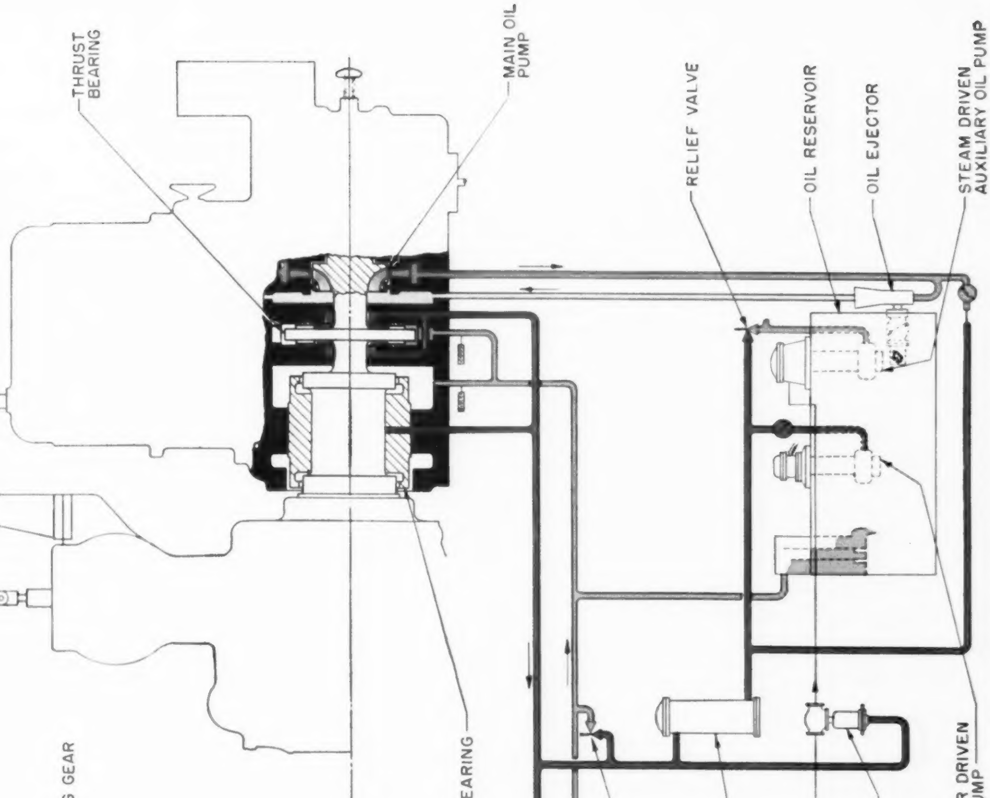
A properly chosen rust-inhibitor must not only perform its rust preventing function without detracting from usual turbine oil properties; it also must not interfere with the operation of the oxidation inhibitor. As a matter of fact, when a proper selection of inhibitors is matched to a particular base oil, the oxidation stability of the resulting rust and oxidation inhibited oil may be not only as good, but actually better than that of the oil containing only the anti-oxidant.

Non-Emulsification

An emulsion is a very intimate mixture of finely divided liquids which are insoluble or only slightly soluble in each other, the mixture being so stable and the liquids so mutually held in suspension that separation due to difference in density may be very slow.

In turbine systems, emulsions are usually formed between the turbine oil and water. Oils of turbine grade are designed to have excellent water-separating characteristics and only emulsify with water in the presence of an emulsion stabilizing medium, which may be oil deterioration products, or very small particles of rust, dirt, or other foreign suspended matter.

Water can enter the turbine lubricating system at the coolers, the sealing glands or from condensation in the sump tank. A careful watch should be kept for the presence of water in the turbine oil; when the amount of water in the system increases



Courtesy of Westinghouse Electric Co.

Figure 2 — Details of the Lubricating Oil System for a Westinghouse steam turbine.

suddenly, the source of contamination should be determined and steps taken to eliminate the condition leading to water entry. Many turbine units are now equipped with vapor extractors on the sump tank which prevent condensation of moisture vapor.

The purification system should be operated on a sufficiently frequent schedule to prevent water build-up and on a continuous basis during periods when appreciable water contamination is occurring. Careful cleaning of the turbine system after erection and proper operation of the purifier should take care of the foreign dirt, and the use of rust-inhibited oils will prevent the formation of rust which can stabilize emulsions.

Foam Resistance

The formation of foam on the surface of the turbine oil in the sump tank indicates the presence of air in the oil. If this air is not removed during the resting period in the sump, it will be recirculated, impeding oil flow to bearings and causing erratic operation of the governor. Since foam results from a mechanical admixture of oil and air, its occurrence will be independent of the characteristics of the oil. Oils do vary, however, in the speed with which they free themselves of air and turbine oils are so manufactured as to exhibit a very rapid rate of air separation. In general, it can be stated that oils of low viscosity free themselves of air more quickly than oils of higher viscosity.

The following list covers the more common conditions which promote air entrainment:

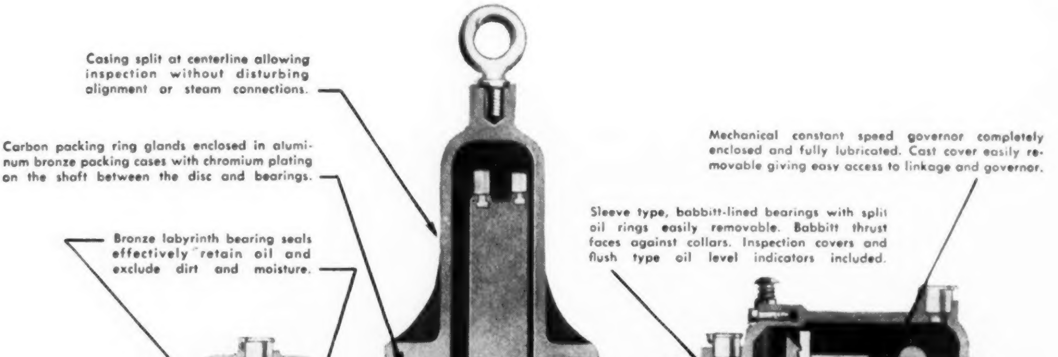
a. Air leakage into the pump suction line.

b. Low oil level, permitting the pump suction inlet to become exposed to air.

c. Insufficient venting of the lubricating system.

d. Excessive splashing from oil return lines to the sump oil level.

e. Oil return lines of insufficient size or capacity.



Courtesy of Murray Iron Works Co.

Figure 3 — Details of the Murray Iron Works type H Single Stage Turbine for mechanical drive.

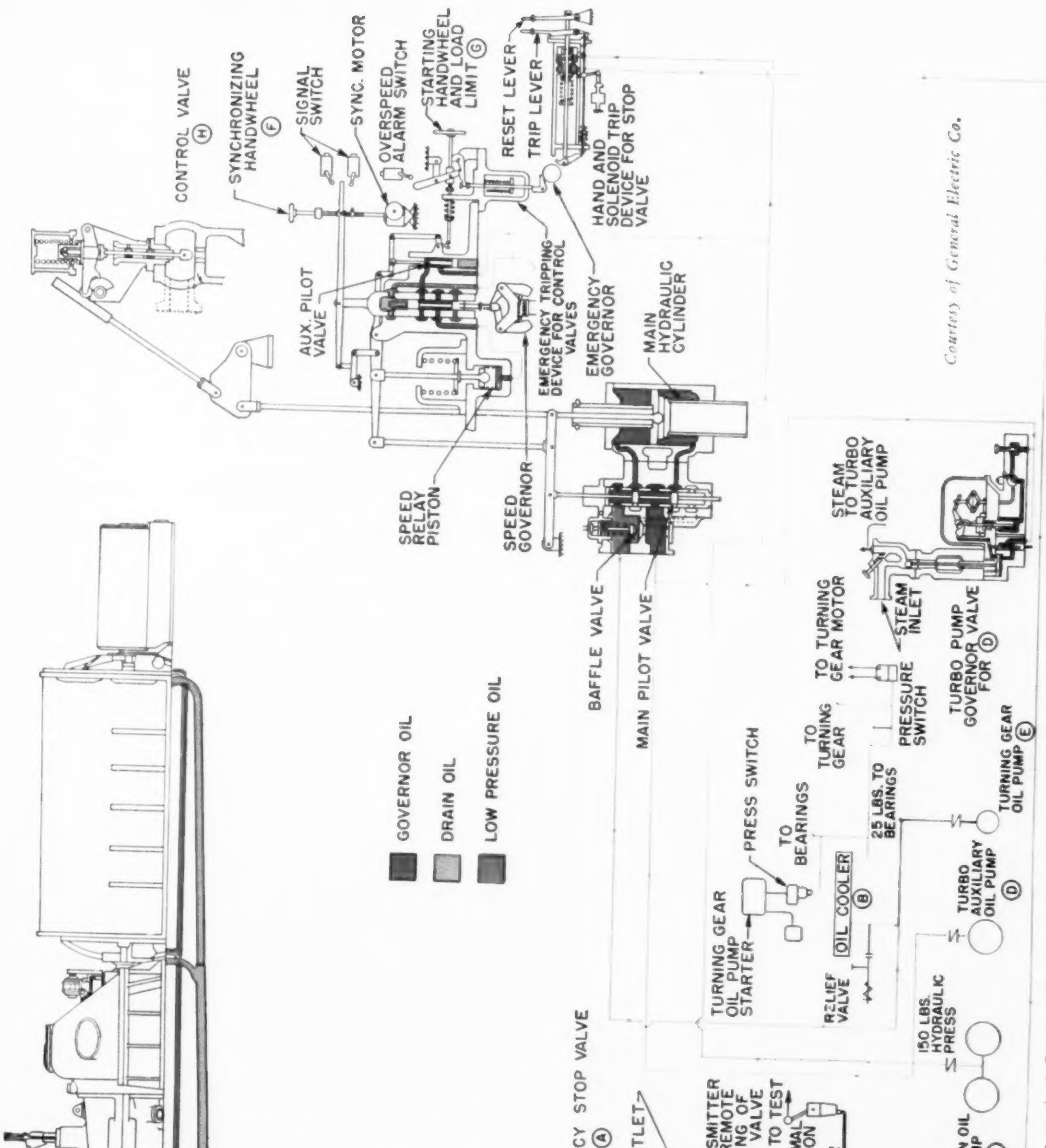
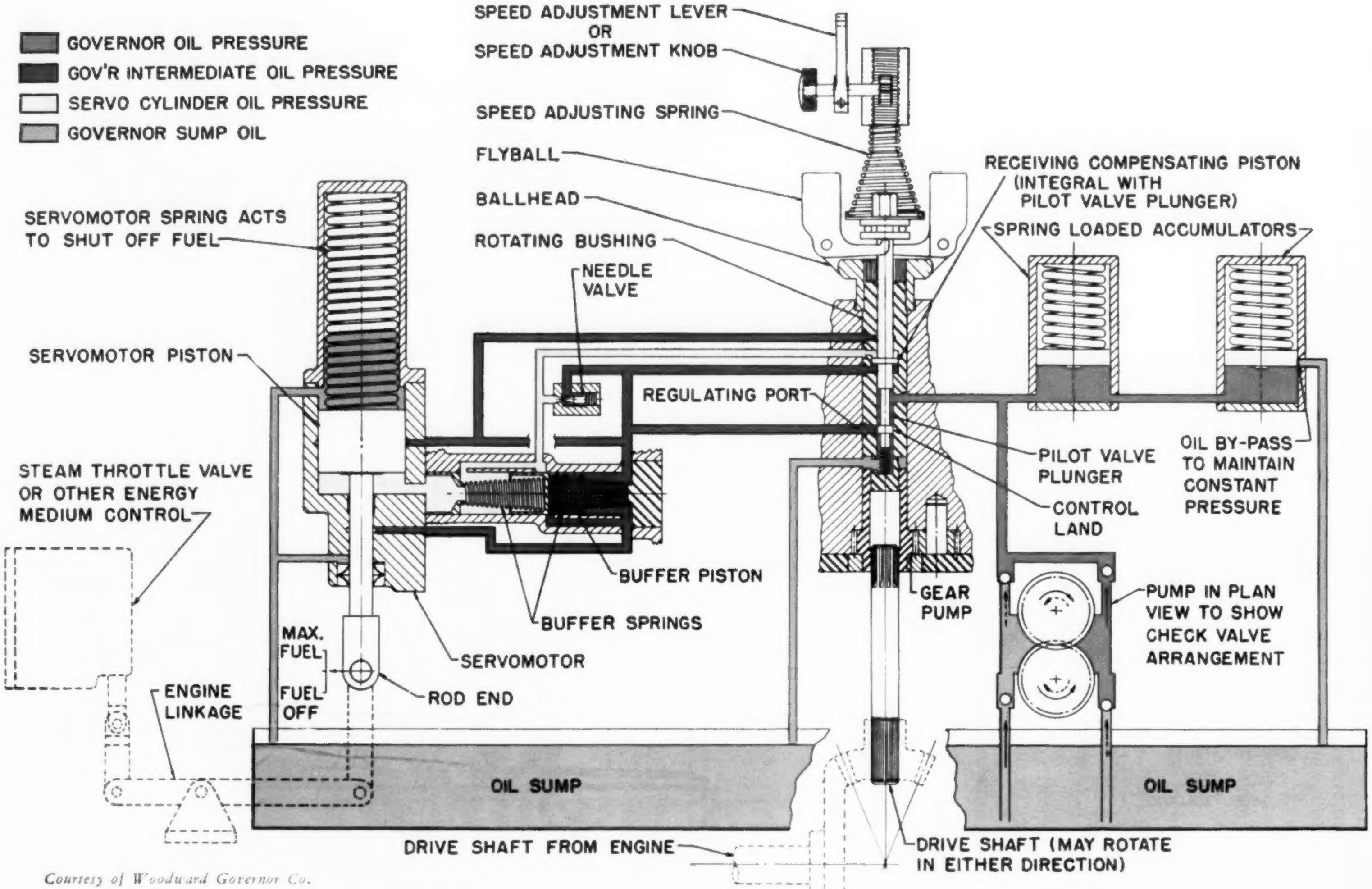
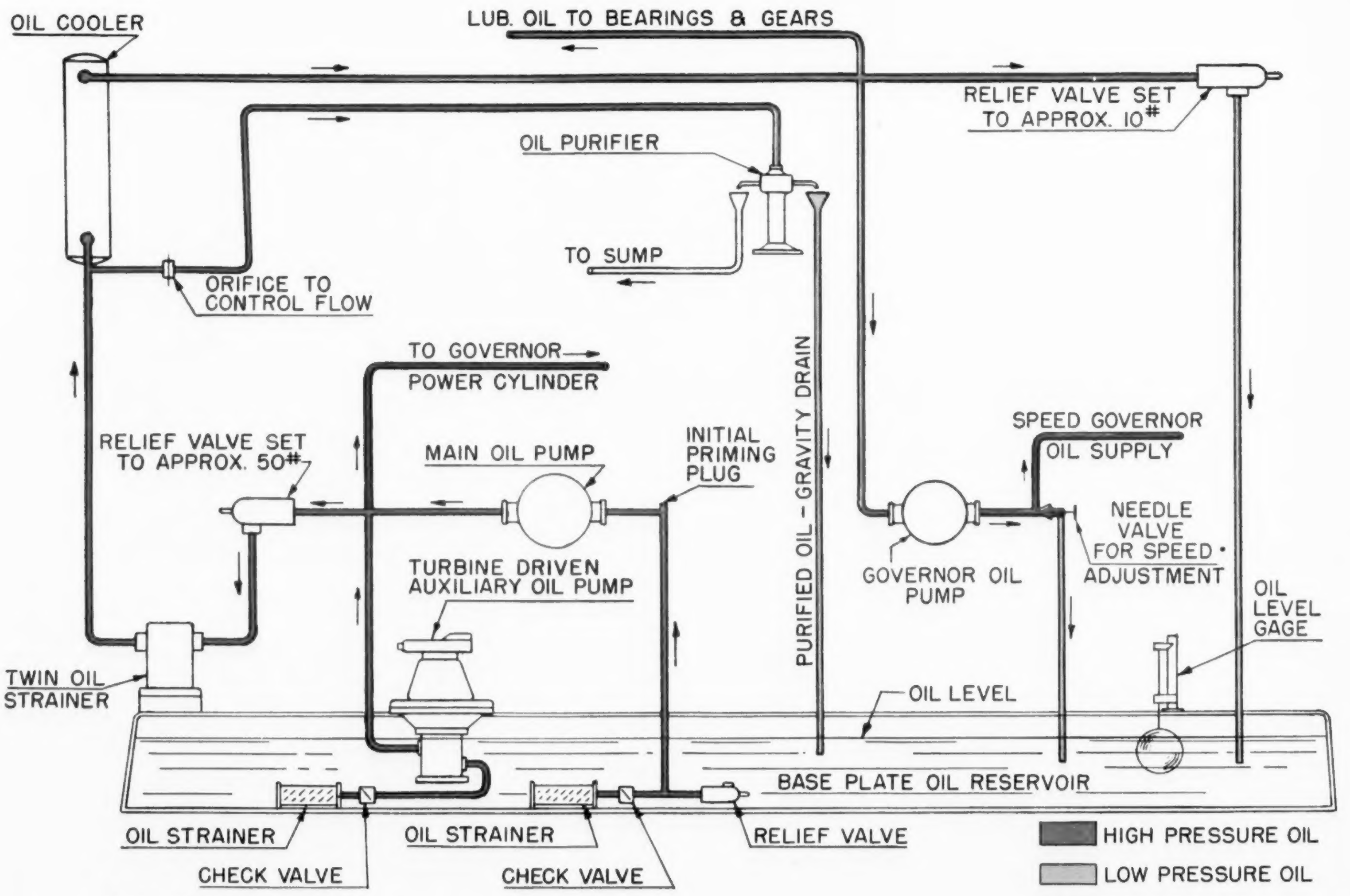


Figure 4 — A typical General Electric steam turbine showing details of the high and low pressure sides of the oiling system.



Courtesy of Woodward Governor Co.

Figure 5 — Showing governor operation features of a Woodward PG governor applicable to steam turbine service.



Courtesy of DeLaval Steam Turbine Co.

Figure 6 — A typical closed pressure oiling system for a DeLaval geared turbine-driven water works pump.

f. Discharge velocity from pressure regulating valve too high with unnecessary splashing and spray above the oil level.

g. Operating of the circulating oil pump at excessive capacity.

h. Wide differences in temperature between fresh oil added and the oil in the system.

i. Vacuum conditions inside bearings.

The correction measures for any of the above conditions are fairly obvious.

OIL RECONDITIONING

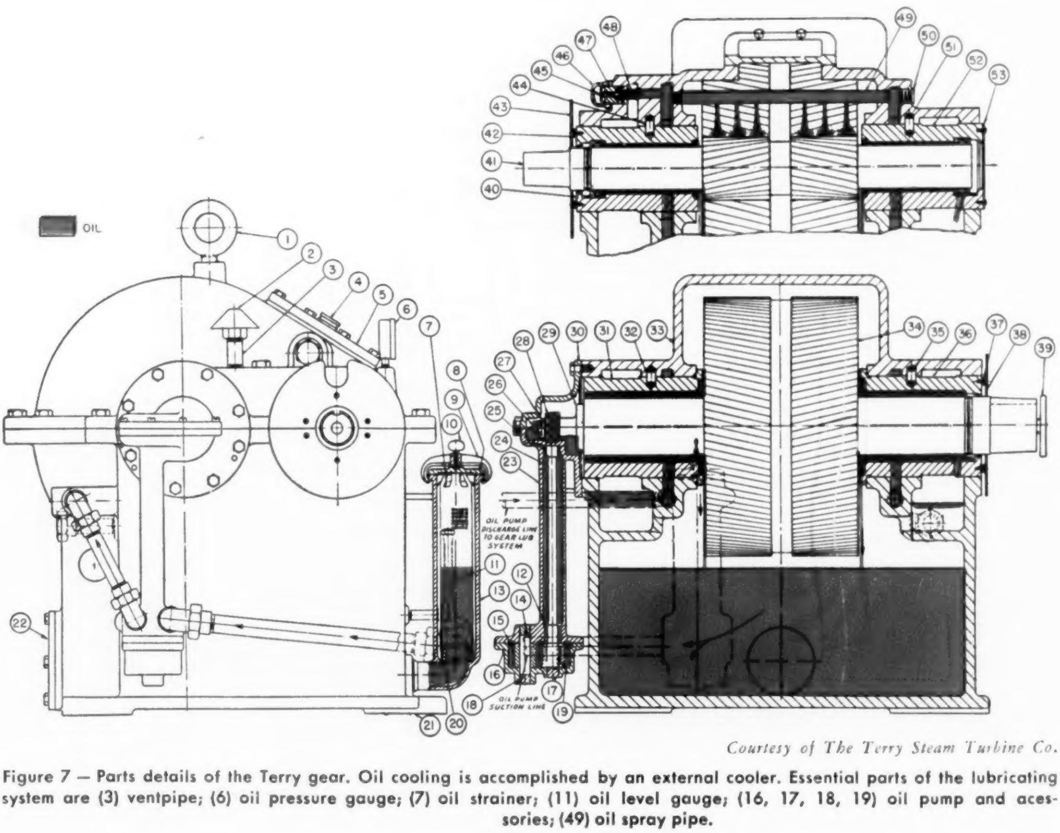
In order to keep a turbine oil in condition for best service, contaminants must be removed continuously or periodically.

The simplest means of effecting at least partial clarification of a used turbine oil is to allow it to stand quietly in some form of settling tank for periods up to several weeks. The clarified oil is decanted from the water and insoluble material which settles to the bottom of the tank. Because of the slow settling rate at higher oil viscosities, the oil in the rest tank must be held at 120-140° F. during the settling period. Settling as a method of purification has a number of disadvantages, among which are the necessity for having two complete batches of oil in service and for shutting the turbine down for changeover.

Centrifuging involves the same basic principles as settling and decantation, but is faster because the separating force is increased several thousand times. The centrifuge can free the oil of suspended insoluble matter, dirt, and water. It cannot remove soluble contaminants. Combinations of water-washing and centrifuging have been used to remove such soluble impurities, but this practice is not recommended with rust and oxidation inhibited turbine oils, because of the possible removal of inhibitors from the turbine oil.

Filters are also used for turbine oil purification. Inert type filters include screens, edge filters, bag filters and filters packed with inert material. Such filters remove suspended materials from the oil and vary in their efficiency with the size of filter orifices. Active-type filters are packed with adsorbent materials such as activated alumina or clay. Active-type filters may remove inhibitors and their use is not recommended with inhibited turbine oils.

Filters which recondition turbine oil by settling followed by passage thru bags and inert packings are used widely and successfully.



Courtesy of The Terry Steam Turbine Co.

Figure 7 — Parts details of the Terry gear. Oil cooling is accomplished by an external cooler. Essential parts of the lubricating system are (3) ventpipe; (6) oil pressure gauge; (7) oil strainer; (11) oil level gauge; (16, 17, 18, 19) oil pump and acessories; (49) oil spray pipe.

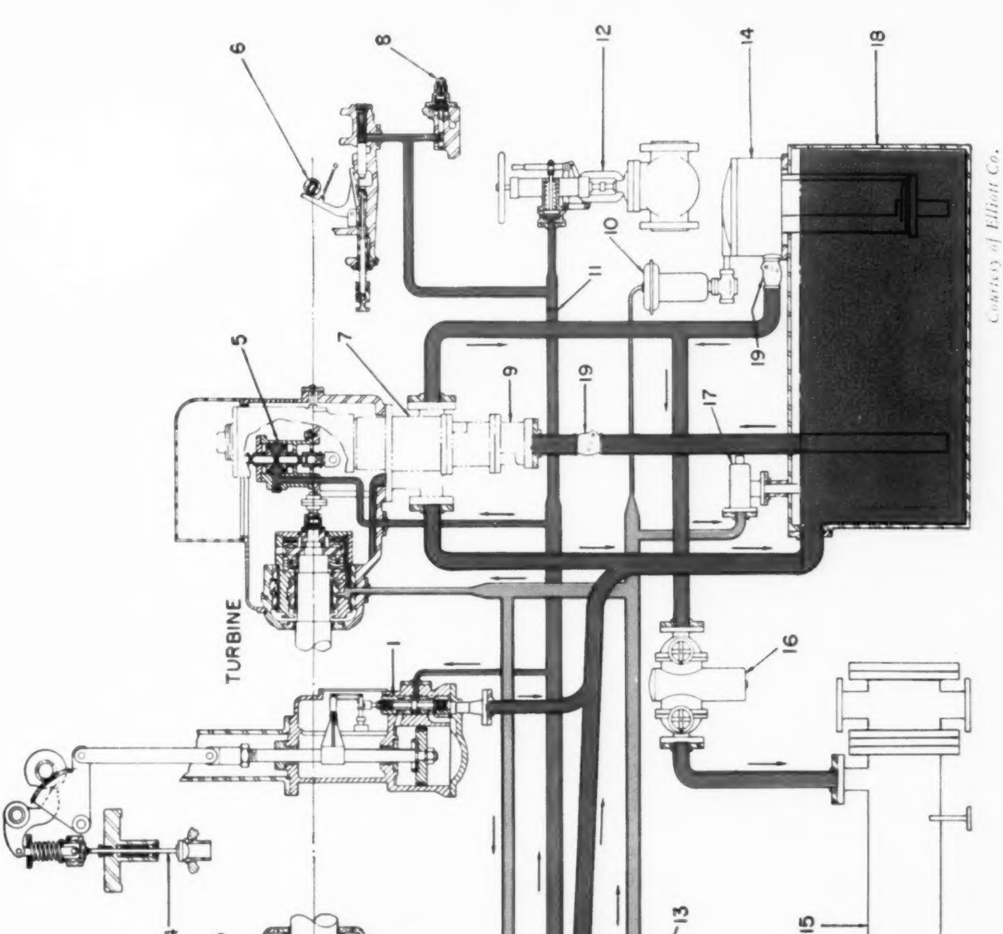
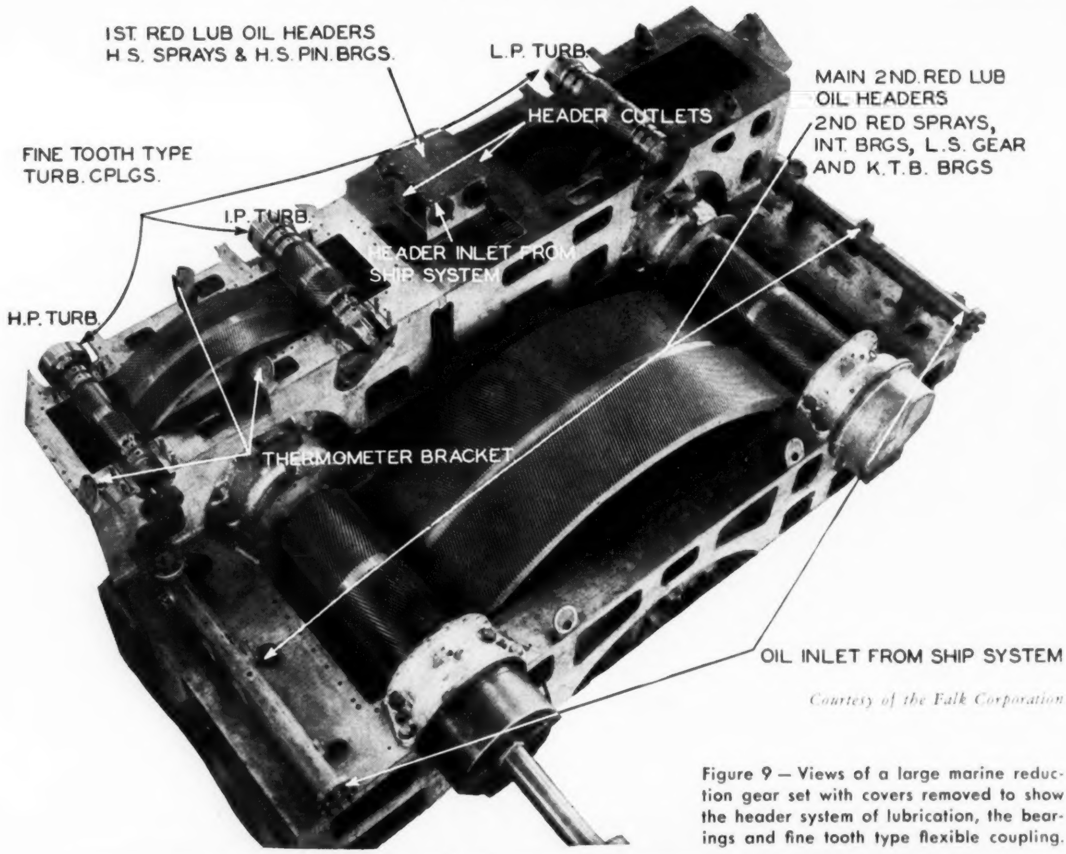
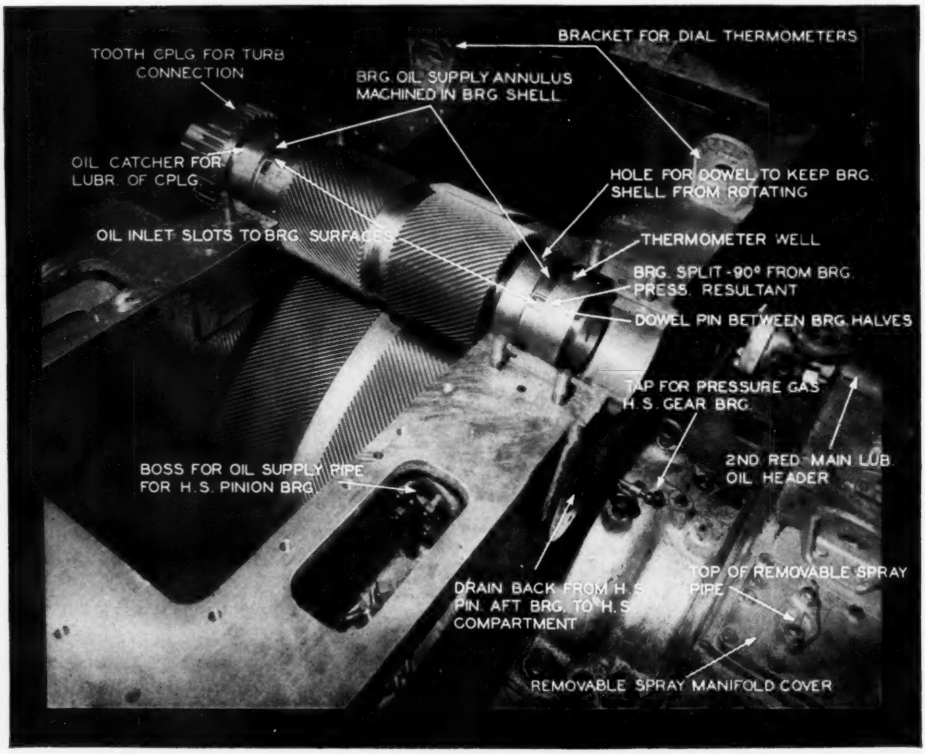


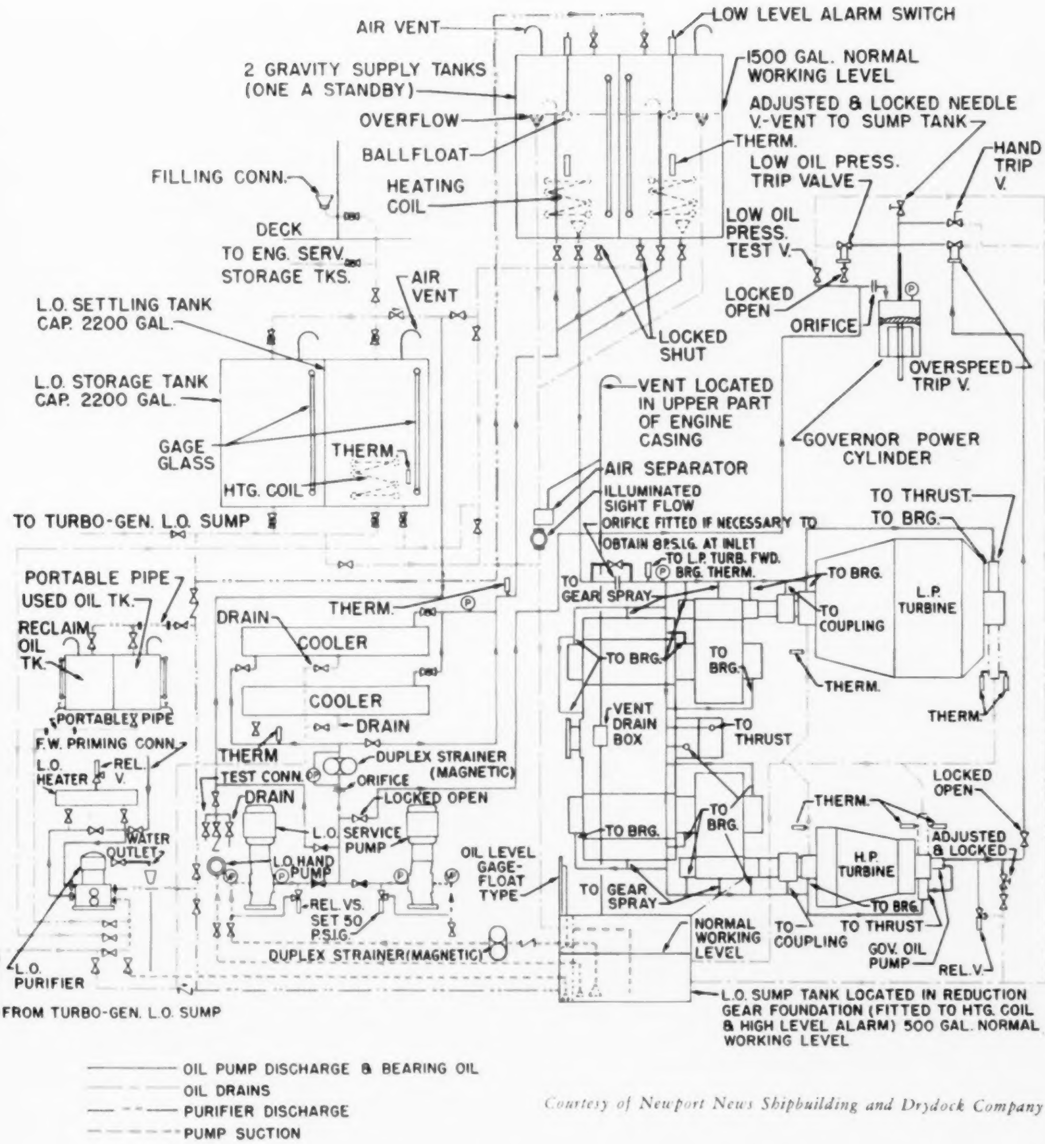
Figure 8 — Typical oiling system for an Elliott turbine generator unit.



Courtesy of the Falk Corporation

Figure 9 — Views of a large marine reduction gear set with covers removed to show the header system of lubrication, the bearings and fine tooth type flexible coupling.





Courtesy of Newport News Shipbuilding and Drydock Company

Figure 10 — Oiling diagram for a Newport News Marine Turbine.

The purification system of a turbine should be regarded as insurance which has been purchased to help guarantee continued satisfactory operation of the turbine system. The oil purification system will keep the turbine oil free from contaminating materials which interfere with operation and may shorten the useful life of the oil. Since it is difficult to determine when contamination is likely to occur and since it is desirable to remove it as quickly as possible, the purification system may well be operated continuously while the turbine is running and the entire batch of oil should be passed through the purifier system during periods of shutdown.

STORAGE STABILITY

The question of storage stability of turbine oils containing rust and oxidation inhibitors has sometimes been raised by turbine operators who were considering the use of these products. The possibility was envisioned that the rust inhibitor concentration would be gradually depleted as a result of "plating out" of the rust inhibitors on the metal surfaces of the drum or storage tank in which the oil is contained. Accelerated tests, as well as tests on products stored under a variety of conditions for several years, have shown that the products marketed by major refiners are stable during storage in contact with metal.

Basic research on the mechanism by which rust inhibitors protect metal surfaces indicates that these rust inhibitors only become active in the presence of water, so that storage under normal conditions presents no problem. Further, the concentration of the rust inhibitors in the turbine oil is sufficiently high, so that where water is present, the depletion in rust inhibitor in the drum or storage tank would represent only a very minor percentage reduction in rust inhibitor content.

CLEANING AND PREPARATION OF TURBINE LUBRICATING SYSTEMS

Recommended practices for the preparation of new turbine lubricating systems and for the cleaning of such systems after service have been prepared by a Joint ASTM-ASME Committee on Turbine Lubrication. These practices represent the opinions of the best-informed sources and their use should be given most thoughtful consideration. A brief resumé of these practices is given here for information.

Preparation of Lubrication System Before Service

The preparation of the lubricating system of a new turbine should be accomplished through the joint efforts of the turbine builder, the operator and the oil supplier. The same care should be exercised on large or small units in land or marine service. No phase of the work should be undertaken without a thorough understanding of the possible effects on subsequent operation, nor should it be entrusted to inexperienced personnel, unless adequately supervised.

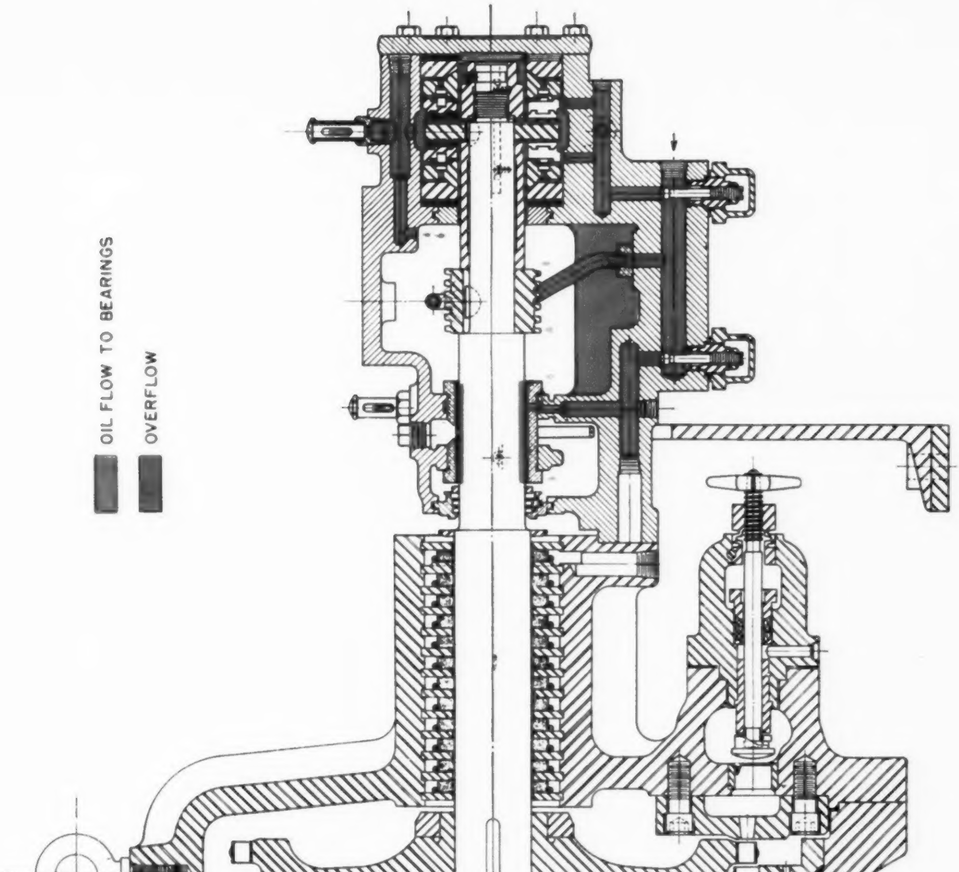
After fabrication and pickling, all piping should be washed with a neutralizing agent, rinsed with clean water and coated inside with a petroleum-base rust preventive readily soluble in turbine oil. All ends should be sealed to prevent entry of foreign matter. All cast-iron parts and oil storage tanks should be thoroughly cleaned by steel-shot blasting or wire brushing and coated with an oil-soluble rust-preventive prior to shipment or storage.

After erection, all accessible parts of the system should be inspected and the system freed of all foreign material (dirt, sand, welding shot, metal chips, grease-like rust preventives, etc.). Rust-preventives which are not readily soluble in turbine oil should be removed completely. In this and subsequent operations, lintless wiping cloths should be used, to prevent accumulation of lint which may plug oil passages.

Blind flanges at bearing inlets and "jumpers" across bearings should be installed to isolate the bearings during the initial flushing. Where this is not possible, the shells of the bearings should be removed or rotated so as to prevent oil flow through them, without interfering with the flow of high-pressure oil. The system should be flushed with an inhibited flushing oil of the same or lower viscosity than the final oil charge. A sufficient charge of flushing oil should be used to permit continuous circulation. During circulation, the flushing oil should be heated to 125-180° F. Heating the flushing oil to a temperature higher than that expected in service is desirable since it will expand the piping and loosen scale and other adhering materials. The flushing oil should be circulated for as long a period as may be necessary; this period may vary from four hours to ninety-six hours, depending upon the size of the unit and its initial cleanliness. Continuous use of a filter or centrifuge during flushing is important. When the system is not equipped with a purifier, an auxiliary filter should be installed.

After the flushing operation, the system should be drained thoroughly, particular care being given to low points in the piping, coolers and governor mechanism. Heavy solids which have been flushed into bearing pedestals and the sump tank should be removed manually and the governor hydraulic system inspected and cleaned, if necessary.

To assure complete removal of the flushing oil and the contaminants which it may carry in solution, it may be desirable to follow up the flushing with a displacement oil, of the same type which is



Courtesy of Worthington Corporation

Figure 11 — Longitudinal Section through a Worthington steam turbine.

to be used later for lubrication. The displacement charge is circulated for a sufficient period of time to indicate that further material is not being accumulated in the filters. The blind flanges and jumpers at bearings may then be removed or the bearing shells rotated or re-installed to permit flushing of the bearings. The governor mechanism should be actuated, to assure flushing of these parts. All accessible bearings should be removed and inspected; if they are found to be in satisfactory condition, the system may be considered clean and can be drained thoroughly. The oil reservoir should be wiped out again and the batch of lubricating oil installed.

Preparation of Lubrication System After Service

During service, there may accumulate in turbine lubricating systems, deposits as a result of contamination by water, insoluble oil degradation products, foreign material (dirt, coal dust, fly-ash, mill scale) and combinations of these. Permanent type protective coatings in oil tanks may become loosened as a result of blistering or flaking. These materials may cause clogging of oil passages, fouling of governors, deposits on coolers and other difficulties. In addition, they may affect the oil and cause it to foam, emulsify with water, or to oxidize at an accelerated rate.

Adequate oil purification during service will go far to prevent build-up of insoluble foreign matter in the lubrication system. Periodic inspections of the lubrication system will indicate whether maintenance practices are adequate. A log of bearing and cooler inlet and outlet temperatures and periodic oil analyses may show whether changes are occurring which might lead to the accumulation of deposits.

Inspection of the coolers or of the turbine lubricating system may show deposits ranging from a viscous oily film to solids which completely choke passages. When an appreciable quantity of deposit is found in a turbine system, it must be removed. The method of cleaning will depend, of course, on the nature and the amount of the insoluble material present. Laboratory examination of a representative sample of the deposit will assist in determining the best method of removal.

For cleaning the oil side of coolers, hot water or steam washing or petroleum flushing oil are usually employed. When the cooler bundles are removed from their place, other cleaning agents may be used. Such agents should not attack the finish of the metal forming the tubes and all traces of the cleaner should be removed before the tube bundle is returned to its place. After cleaning, hydrostatic tests should be made on coolers to test for leaks.

Tarry matter from oil degradation products and oil-water emulsions can often be removed by steam or hot water washing. Parts should be steamed or washed out and dried with dry hot air. Bearings and governor mechanism should be cleaned manually. Since steaming will remove protective films from metals, the system should be assembled and rust-inhibited flushing or turbine oil circulated as quickly as possible after cleaning.

Cleaning with rust-inhibited flushing oil is a convenient method of removing deposits from a turbine system. The complexity and inaccessibility of piping in marine turbine systems is such that this procedure is used in almost all cases where marine systems must be cleaned. A sufficient charge of the inhibited flushing oil to permit continuous circulation is heated to 150-180° F. and circulated for four to twenty-four hours. The oil purifier of the unit or an auxiliary filter, if the unit is not so equipped, should be operated on a continuous by-pass basis, during the entire flushing operation. Bearings and governor should be by-passed during the initial stages of the flushing, until it has been established that the major portion of the deposits has been removed. After flushing has been completed, the system should be inspected and any remaining deposits removed by wiping with clean lintless cloths.

In some instances, where a lightly-sludged unit cannot be taken out of service for a sufficient time for thorough cleaning prior to an oil change, continuous by-pass circulation of the oil in the system through a clay filter has been used to remove suspended solids and partially-soluble oil deterioration products. When such a procedure is employed, governor operation and bearing temperatures should be watched carefully since solid particles may be loosened, which are large enough to restrict oil flow and interfere with operation.

It will, of course, be appreciated that operating demands and facilities available on the job will dictate, to a large extent, the procedure which can be followed in cleaning a turbine lubricating system. The most careful supervision and inspection at various stages of the flushing operation are necessary to establish absolutely that all foreign materials which could interfere with subsequent operation have been removed.

SUMMARY

The modern steam turbine is making increasing demands upon turbine lubricating oil. To date, these demands have been satisfied by the use of rust and oxidation inhibited turbine oils, coupled with scrupulous attention to maintenance practices. It is expected that continued close cooperation between turbine operators, manufacturers and oil refiners will take care of future demands, as they arise.

Printed in U. S. A. by
Salley & Collins, Inc.
305 East 45th Street
New York 17, N. Y.